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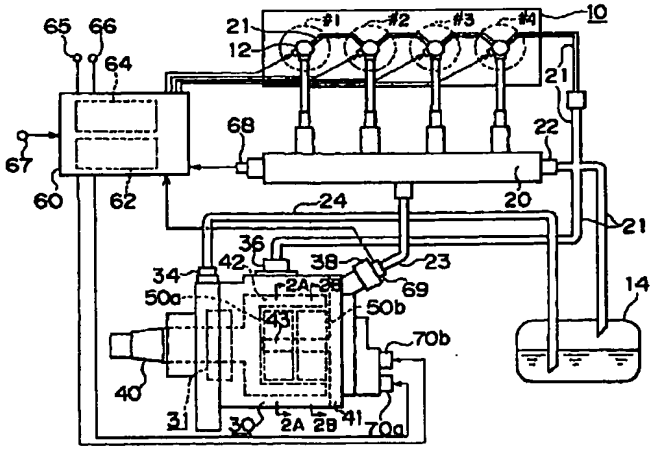
(54) Method of determining abnormality in high-pressure fuel injection device

(57) The present invention provides a method of determining abnormality, which is capable of specifying a fuel force-feed system subject to an abnormality without causing fluctuations of a fuel pressure in an accumulator line. A fuel pump (30) is provided with a first supply pump (50a) and a second supply pump (50b), and these supply pumps (50a, 50b) alternately force-feed fuel to a common rail (20). Respective fuel injection valves (12) carry out fuel injection based on a fuel pressure (rail pressure) in the common rail (20). An ECU (60) detects a rail pressure rise amount during a fuel force-feed period and calculates an estimated value of rail pressure rise amount based on a force-feed command value for the fuel pump (30). The ECU (60) determines which one of the supply pumps (50a, 50b) is in the process of force-feeding fuel in a certain fuel force-feed period, and determines individually the occurrence of an abnormality in the respective supply pumps (50a, 50b) based on the detected value and the estimated value of rail pressure rise amount.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a method of determining abnormality in a high-pressure fuel injection device having a plurality of fuel force-feed systems for force-feeding high-pressure fuel in individual force-feed periods to an accumulator line to which fuel injection valves of an internal combustion engine are connected.

2. Description of the Related Art

[0002] As a high-pressure fuel injection device applied to a diesel engine or a cylinder injection type gasoline engine, there is known an accumulator type high-pressure fuel injection device that force-feeds fuel from a fuel pump to an accumulator line such as a common rail and supplies fuel to combustion chambers of the engine through fuel injection valves connected to the accumulator line by opening and closing the fuel injection valves.

[0003] Some high-pressure fuel injection devices of this type are provided with a plurality of fuel force-feed systems, for example, two fuel force-feed pumps. Provision of a plurality of fuel force-feed systems makes it possible to improve fuel force-feed performance and to suitably inhibit fluctuations of a fuel pressure in the accumulator line, namely, a fuel injection pressure.

[0004] A known method of determining abnormality in such a high-pressure fuel injection device includes the steps of detecting an amount of rise in fuel pressure in the accumulator line resulting from force-feeding of fuel from the respective fuel force-feed systems, and determining, if the difference between the fuel pressure rise amount and a target amount (i.e. a fuel pressure rise amount during normal operation) has become greater than a predetermined threshold value, that there is an abnormality occurring. According to this method of determining abnormality, in order to avoid miss-determination based on a detection error of fuel pressure rise amount, the difference between the fuel pressure rise amount and the target amount in the accumulator line is subjected to an averaging processing as regards a plurality of fuel force-feed operations.

[0005] However, in such a method of determining abnormality, even if operational failure has occurred in one or some of the fuel force-feed systems, the difference is reduced by the averaging processing. Hence, such operational failure may not be regarded as the occurrence of abnormality. It may be possible to detect such abnormality by setting the threshold value smaller. However, setting the threshold value smaller tends to cause miss-determination. Also, in this method of determining abnormality, even if the occurrence of abnormality in one or some of the fuel force-feed systems can be determined precisely, it is impossible to determine with which of the fuel force-feed systems the abnormality is associated.

[0006] In view of this problem, Japanese Patent Application No. HEI 4-272472 proposes a method of determining abnormality as will be described below.

[0007] In this method of determining abnormality, first of all, a change in fuel pressure in a common rail during operation of both two fuel force-feed systems (high-pressure pumps) is stored as a reference pressure pattern PSTD. Then, operation of one of the two high-pressure pumps is forcibly suspended, and a change in fuel pressure at this moment is stored as a first suspension pressure pattern P#1. Furthermore, operation of the other high-pressure pump is forcibly suspended, and a change in fuel pressure at this moment is stored as a second suspension pressure pattern P#2. By comparing the reference pressure pattern PSTD with the respective suspension pressure patterns P#1 and P#2, it is determined whether or not there is an abnormality occurring in the respective high-pressure pumps.

[0008] If both the high-pressure pumps are in normal operation, upon forcibly suspending operation of one of them, the fuel pressure in the common rail fluctuates, and the reference pressure pattern PSTD and the suspension pressure pattern P#1 (or P#2) assume different values. Conversely, if there is an abnormality occurring in one of the high-pressure pumps, even after suspending operation of the high-pressure pump subject to the abnormality, the fuel pressure does not change, and one of the suspension pressure patterns P#1 and P#2 that corresponds to suspension of the pump subject to the abnormality may coincide with the reference pressure pattern PSTD.

[0009] Accordingly, by determining whether or not the respective suspension pressure patterns P#1 and P#2 coincide with the reference pressure pattern PSTD, the occurrence of abnormality in the respective high-pressure pumps can be determined individually.

[0010] However, this known method of determining abnormality requires suspending, even though temporarily, operation of the respective high-pressure pumps when storing the aforementioned suspension pressure patterns P#1 and P#2. Therefore, as disclosed in the aforementioned patent publication, if such determination of abnormality is made on condition that the engine is in its idling state, the amount of fuel injection changes due to fluctuations of fuel pressure caused upon suspension of the respective high-pressure pumps. As a result, a so-called rough idling state wherein the

engine rotational speed fluctuates drastically may arise.

[0011] As described hitherto, according to the previously employed method of determining abnormality, the fuel pressure in the common rail fluctuates independently of a requirement on the side of the engine, which inevitably causes deterioration of precision of fuel injection control and resultant deterioration of a combustion state of the engine.

SUMMARY OF THE INVENTION

[0012] The present invention has been made in view of such circumstances. It is an object of the present invention to provide a method of determining abnormality, which is applied to a high-pressure injection device having a plurality of fuel force-feed systems and is capable of specifying a fuel force-feed system subject to abnormality without causing fluctuations of a fuel pressure in an accumulator line.

[0013] In order to achieve the above-stated object, according to an aspect of the present invention, there is provided a method of determining abnormality in a high-pressure fuel injection device having a plurality of fuel force-feed systems for force-feeding high-pressure fuel in individual force-feed periods to an accumulator line to which fuel injection valves of an internal combustion engine are connected, characterized by comprising the steps of determining which one of the fuel force-feed systems is in a force-feed period at a timing when determination of abnormality is made, and determining whether or not there is an abnormality occurring in each of the fuel force-feed systems.

[0014] In this manner, the occurrence of abnormality can be determined individually without changing operational states of the respective fuel force-feed systems at all. Accordingly, it is possible to specify a fuel force-feed system subject to abnormality without causing fluctuations of a fuel pressure in the accumulator line.

[0015] Although this summary does not describe all the features of the present invention, it should be understood that any combination of the features stated in the dependent claims is within the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

Fig. 1 is a schematic view of the structure of a high-pressure fuel injection device of a diesel engine.
Fig. 2 is a constructive view of the structure of a partial cross-section of a fuel pump and the structure of a fuel passage.
Fig. 3 is a timing chart showing a pattern of change in rail pressure.
Fig. 4 is a flowchart for determining abnormality of the high-pressure fuel injection device.
Fig. 5 is a flowchart for determining abnormality of the high-pressure fuel injection device.
Fig. 6 is a timing chart showing a pattern of change in rail pressure at the time of occurrence of abnormality.
Fig. 7 is an illustrative view illustrating a relationship between abnormality determining values and patterns of abnormality in respective fuel force-feed systems.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] One embodiment of the present invention applied to a high-pressure fuel injection device of a four-cylinder direct injection diesel engine (hereinafter referred to simply as the „engine") will be described hereinafter.

[0018] Fig. 1 schematically shows the structures of an engine 10 and a high-pressure fuel injection device thereof.

[0019] The high-pressure fuel injection device is provided with injectors 12 corresponding to respective cylinders #1 through #4 of the engine 10, a common rail 20 to which the respective injectors 12 are connected, a fuel pump 30 for force-feeding fuel in a fuel tank 14 to the common rail 20, and an electronic control unit (hereinafter referred to as the „ECU") 60.

[0020] The common rail 20 functions as an accumulator line for accumulating fuel supplied from the fuel pump 30 at a predetermined pressure. A fuel injection pressure of the injectors 12 is determined based on a fuel pressure in the common rail 20 (hereinafter referred to as a „rail pressure"). A relief valve 22 is attached to the common rail 20. The relief valve 22 is connected to the fuel tank 14 through a relief passage 21.

[0021] The relief valve 22, which is normally kept closed, opens when the rail pressure becomes equal to or higher than a predetermined upper limit set pressure because of some abnormality, thereby forcibly reducing the rail pressure. If the rail pressure falls drastically due to the opening of the relief valve 22, the ECU 60 determines that fuel has leaked out, and suspends fuel injection so as to forcibly suspend operation of the engine 10.

[0022] The injectors 12, which are electromagnetic valves that are driven to be opened and closed by the ECU 60, inject fuel supplied from the common rail 20 to combustion chambers (not shown) of the respective cylinders #1 through #4. The respective injectors 12 are also connected to the fuel tank 14 through the relief passage 21. Even when the injectors 12 are all closed, part of the fuel supplied from the common rail 20 to the respective injectors 12 constantly

leaks out to the interior of the injectors 12. The fuel that has thus leaked out is returned to the fuel tank 14 through the relief passage 21.

[0023] The ECU 60 performs control operations relating to force-feeding of fuel from the fuel pump 30 and fuel injection from the injectors 12. The ECU 60 is composed of a memory 64 in which various control programs, functional data and the like are stored, of a CPU 62 for performing arithmetic processings, and of other components.

[0024] Various sensors for detecting an operational state of the engine 10, a state of fuel in the common rail 20 and the like are connected to the ECU 60. Detection signals from those sensors are inputted to the ECU 60.

[0025] A rotational speed sensor 65 is provided in the vicinity of a crank shaft (not shown) of the engine 10, and a cylinder discriminating sensor 66 is provided in the vicinity of a cam shaft (not shown). Based on detection signals inputted from those sensors 65 and 66, the ECU 60 calculates a rotational speed of the crank shaft (engine rotational speed NE) and a rotational angle of the crank shaft (crank angle CA) respectively.

[0026] An accelerator sensor 67, which is provided in the vicinity of an accelerator (not shown), outputs a detection signal corresponding to a depression amount of the accelerator (accelerator opening degree ACCP). A fuel pressure sensor 68, which is provided in the common rail 20, outputs a detection signal corresponding to a rail pressure. A fuel temperature sensor 69, which is provided in the vicinity of a discharge port 38 of the fuel pump 30, outputs a detection signal corresponding to a temperature of fuel (fuel temperature THF). Based on detection signals from the respective sensors 67 through 69, the ECU 60 detects an accelerator opening degree ACCP, a rail pressure and a fuel temperature THF respectively.

[0027] The fuel pump 30 is provided with a drive shaft 40 rotationally driven by the crank shaft of the engine 10, a feed pump 31 operating based on rotation of the drive shaft 40, a pair of supply pumps (a first supply pump 50a and a second supply pump 50b) driven by an annular cam 42 formed on the drive shaft 40, a pair of adjusting valves (a first adjusting valve 70a and a second adjusting valve 70b) for adjusting amounts of fuel force-fed from the supply pumps 50a and 50b, and the like.

[0028] The fuel pump 31 sucks fuel in the fuel tank 14 from a suction port 34 through a suction passage 24, and supplies the fuel to the first supply pump 50a and the second supply pump 50b at a predetermined feed pressure.

[0029] Both the first supply pump 50a and the second supply pump 50b are so-called inner cam type pumps. These pumps pressurize fuel supplied from the feed pump 31 to a higher pressure (e.g. 25 to 180 MPa) and force-feeds the pressurized fuel to the common rail 20 from the discharge port 38 through a discharge passage 23.

[0030] Fig. 2 schematically shows cross-sectional structures of the respective supply pumps 50a and 50b taken along lines 2A-2A and 2B-2B in Fig. 1 respectively, and a structure of fuel passages in the fuel pump 30. Fig. 3 is a timing chart showing, in a manner corresponding to crank angle CA, a pattern of change in rail pressure during normal operation, operations of sucking fuel into and force-feeding fuel from the respective supply pumps 50a and 50b, and the like.

[0031] As shown in Fig. 2, the first supply pump 50a is provided with a cylindrical supporting portion 43 formed in a housing 41 (see Fig. 1) of the fuel pump 30, a pair of plungers 54a reciprocally movably supported on a through hole 43a formed in the supporting portion 43 and the like, a first pressurizing chamber 52a defined by inner end faces of the respective plungers 54a and an inner wall of the through hole 43a, and the like. A shoe 55a, on which a roller 56a is rotatably supported, is formed at an outer end portion of each of the plungers 54a.

[0032] The cam 42 has elliptical cam faces 42c on which the respective rollers 56a can abut. Therefore, when the cam 42 rotates in accordance with rotation of the drive shaft 40, the distance La between the cam faces 42c in a direction in which the respective plungers 54a reciprocate changes in accordance with the rotation of the cam 42. Accordingly, if the cam 42 rotates with the respective rollers 56a abutting on the cam faces 42c, the respective plungers 54a reciprocate such that they approach each other and become spaced apart from each other. The volume in the first pressurizing chamber 52a changes in accordance with reciprocating movements of the respective plungers 54a. Hereinafter, the period during which the distance La between the cam faces 42c will be referred to as a „suction stroke" of the first supply pump 50a, and the period during which the distance La decreases will be referred to as a „force-feed stroke".

[0033] The drive shaft 40, whose reduction ratio with respect to the crank shaft is set to 1/2, rotates by one revolution while the crank shaft rotates by two revolutions. Accordingly, as shown in Fig. 3, while one cycle of operation made up of intake, compression, explosion and exhaust is performed in the respective cylinders #1 through #4 based on rotation of the crank shaft by two revolutions (i.e. in the period over which the crank angle CA changes by 720°CA (CA: Crank Angle)), the suction stroke and the force-feed stroke are alternately performed twice in the first supply pump 50a.

[0034] As shown in Fig. 2, the first pressurizing chamber 52a is connected to the feed pump 31 through a check valve 44a and the first adjusting valve 70a, and is connected to the discharge port 38 through another check valve 46a. The check valves 44a and 46a regulates flow of fuel from the first pressurizing chamber 52a toward the feed pump 31 and flow of fuel from the discharge port 38 toward the first pressurizing chamber 52a respectively, such that the fuel always flows in a direction from the feed pump 31 through the first supply pump 50a to the common rail 20.

[0035] The components described hitherto, namely, the first supply pump 50a, the first adjusting valve 70a, the

check valves 44a and 46a, the common rail 20, the feed pump 31 and the respective fuel passages connecting those components with one another, constitute a first fuel force-feed system.

[0036] In the first fuel force-feed system, if the first adjusting valve 70a opens during a suction stroke of the first supply pump 50a, fuel is supplied from the feed pump 31 through the check valve 44a to the first pressurizing chamber 52a. In a force-feed stroke that follows, all the fuel that has been supplied to the first pressurizing chamber 52a is force-fed to the discharge port 38 from the first pressurizing chamber 52a through the check valve 46a.

[0037] On the other hand, the second supply pump 50b has substantially the same construction as the first supply pump 50a. That is, the second supply pump 50b is provided with a second pressurizing chamber 52b, a plunger 54b, a shoe 55b, a roller 56b and the like. The second pressurizing chamber 52b is connected to the feed pump 31 through the check valve 44b and the second adjusting valve 70b, and is connected to the discharge port 38 through another check valve 46b.

[0038] A through hole 43b for reciprocally supporting the plunger 54b is formed in the second supply pump 50b in such a manner as to extend perpendicularly to a direction in which the through hole 43a of the first supply pump 50a extends. Thus, if the period in which the distance Lb between the cam faces 42c in a direction in which the respective plungers 54b reciprocate increases is defined as a „suction stroke" of the second supply pump 50b and the period in which the distance Lb decreases is defined as a „force-feed stroke", the suction stroke and the force-feed stroke of the second supply pump 50b are offset from the suction stroke and the force-feed stroke of the first supply pump 50a respectively by a crank angle of 180°CA, as can be seen from Fig. 3.

[0039] The components described hitherto, namely, the second supply pump 50b, the second adjusting valve 70b, the respective check valves 44b and 46b, the common rail 20, the feed pump 31 and the respective fuel passages connecting those components with one another, constitute a second fuel force-feed system.

[0040] The discharge port of the feed pump 31 is connected to a relief valve 32 as well as the respective adjusting valves 70a and 70b. The relief valve 32 is further connected to the fuel tank 14 by the relief passage 21 through a relief port 36. If the adjusting valves 70a and 70b are closed in a suction stroke of the respective supply pumps 50a and 50b, the relief valve 32 opens due to a pressure of fuel discharged from the feed pump 31. The fuel is returned to the fuel tank 14 through the relief passage 21.

[0041] In those respective fuel force-feed systems, amounts of fuel force-fed from the supply pumps 50a and 50b are adjusted by changing valve-closing timings (crank angles CA) of the adjusting valves 70a and 70b respectively during a suction stroke.

[0042] For example, as indicated by alternate long and short dash lines in (c) and (d) of Fig. 3, if the valve-closing timing of the first adjusting valve 70a is retarded so as to increase an open-valve period thereof, the fuel suction period of the first supply pump 50a is prolonged, so that the fuel suction amount increases. The timing for starting force-feeding fuel is advanced by an amount of retardation of the valve-closing timing of the first adjusting valve 70a and the fuel force-feed period is prolonged, so that the fuel force-feed amount increases.

[0043] Conversely, as indicated by alternate long and two short dashes lines in (c) and (d) of Fig. 3, if the valve-closing timing of the first adjusting valve 70a is advanced so as to reduce an open-valve period thereof, the fuel suction period of the first supply pump 50a is shortened, so that the fuel suction amount decreases. The timing for starting force-feeding fuel is retarded by an amount of advancement of the valve-closing timing of the first adjusting valve 70a and the fuel force-feed period is shortened, so that the fuel force-feed amount decreases.

[0044] The same is true with the second supply pump 50b (see (f) in Fig. 3). That is, the amount of fuel force-fed from the second supply pump 50b can be changed by retarding or advancing a valve-closing timing (see (e) in Fig. 3) of the second adjusting valve 70b. The ECU 60 performs feedback control of amounts of fuel force-fed from the respective supply pumps 50a and 50b based on a difference between a rail pressure detected by the fuel pressure sensor 68 and a target rail pressure set on the basis of an operational state of the engine.

[0045] In this manner, in the respective supply pumps 50a and 50b, when the amounts of fuel force-fed are changed, the timing for terminating sucking fuel and the timing for starting force-feeding fuel are changed. However, both the timing for starting sucking fuel and the timing for terminating force-feeding fuel are set to constant timings (crank angles CA). Also, the amount of fuel force-fed per unit crank angle CA in a fuel force-feed period is constant regardless of the timing for starting force-feeding fuel. Accordingly, the total amount of fuel force-fed from the respective supply pumps 50a and 50b can be calculated based on a fuel force-feed period (crank angle CA) that is calculated from command values for valve-closing timings of the respective adjusting valves 70a and 70b.

[0046] Referring to Fig. 3, (a) represents a pattern of change in rail pressure. The rail pressure constantly changes, namely, increases owing to force-feeding of fuel (see (d) and (f) in Fig. 3) from the respective pumps 50a and 50b and decreases owing to fuel injection (see (b)). In the fuel pump 30 of the present embodiment, the valve-opening timings of the respective adjusting valves 70a and 70b are limited to a certain range so as to prevent force-feeding of fuel and fuel injection from being carried out simultaneously. Accordingly, force-feeding of fuel from the respective supply pumps 50a and 50b is started after termination of fuel injection in any of the cylinders #1 through #4, and is terminated before the start of subsequent fuel injection.

[0047] Further, even in a period in which neither force-feeding of fuel nor fuel injection is carried out, the rail decreases slightly. As described above, this is because part of the fuel supplied from the common rail 20 to the respective injectors 12 is returned to the fuel tank 14 through the relief passage 21.

[0048] Referring to Fig. 3, (g) represents a timing for detecting an after-force-feed fuel pressure PCPR, which is a value of rail pressure immediately after termination of force-feeding of fuel from the respective supply pumps 50a and 50b. The timing for detecting an after-force-feed fuel pressure PCPR is set to a predetermined timing immediately after termination of force-feeding of fuel (a timing at which the crank angle CA reaches CAA0, CAA1, CAA2, CAA3, CAA4, ...in Fig. 3).

[0049] Referring to Fig. 3, (h) represents a timing for detecting a before-force-feed fuel pressure PCRI, which is a value of fuel pressure before the start of force-feeding of fuel from the respective supply pumps 50a and 50b after termination of fuel injection in the respective cylinders #1 through #4. Even after the timing for fuel injection and the period for force-feeding of fuel have been changed, after fuel injection, the timing for detecting a before-force-feed fuel pressure PCRI is always set to a timing before the start of force-feeding of fuel (a timing at which the crank angle CA reaches CAB1, CAB2, CAB3, ...in Fig. 3).

[0050] Both the after-force-feed fuel pressure PCPR and the before-force-feed fuel pressure PCRI are detected through an individual processing routine that is performed by the ECU 60 every time the crank shaft rotates by a predetermined crank angle (180 °CA), and are stored in the memory 64.

[0051] Referring to Fig. 3, (i) represents a pattern of change in determination counter value CPCYLND. The determination counter value CPCYLND is a counter value for determining which of the respective fuel force-feed systems is in the process of force-feeding fuel in a period in which the rail pressure changes from the before-force-feed fuel pressure PCRI to the after-force-feed fuel pressure PCPR. The counter value is set through a processing routine that is performed by the ECU 60 every time the crank shaft rotates by a predetermined crank angle (180 °CA), according to a pattern such as [...0→1→2→3→0→...].

[0052] For example, as shown in Fig. 3, if the determination counter value CPCYLND at the timing (CAA0 through CAA4) for detecting the after-force-feed fuel pressure PCPR is set to „1" or „3", the fuel force-feed period immediately before the detection timing can be determined to be a period during which the first supply pump 50a has performed force-feeding of fuel. If the determination counter value CPCYLND is set to „0" or „2", the fuel force-feed period immediately before the detection timing can be determined to be a period in which the second supply pump 50a has performed force-feeding of fuel.

[0053] Next, a processing of determining abnormality in the high-pressure fuel injection device will be described. This processing of determining abnormality is designed to detect an amount of rise in rail pressure resulting from force-feeding of fuel from the respective fuel force-feed systems, to estimate an amount of rise in rail pressure based on operation of the respective fuel force-feed systems, and to individually determine abnormality in the respective fuel force-feed systems by comparing the detected value with the estimated value.

[0054] If the fuel force-feed systems operate normally, there is a certain correlation between an actually detected fuel pressure and a force-feed command value for the fuel force-feed systems or a change in fuel pressure estimated based on the command value. However, once an abnormality occurs in the fuel force-feed systems, the correlation is weakened. Such weakening of the correlation can be determined with ease by comparing an actually detected change in fuel pressure with a force-feed command value or a change in fuel pressure estimated based on the force-feed command value. The change in fuel pressure may be an amount of change in fuel pressure, a rate of change in fuel pressure, a pattern of change in fuel pressure, or the like.

[0055] Hereinafter, a detailed processing procedure of determining abnormality will be described in detail with reference to flowcharts shown in Figs. 4 and 5. An „abnormality determining routine" shown in these flowcharts is carried out by the ECU 60 as an interruption handling at intervals of a predetermined crank angle (180 °CA). The interruption is carried out at a timing immediately after the timing for detecting an after-fuel-feed fuel pressure PCPR (any of the timings CAA1 through CAA4 shown in Fig. 3).

[0056] First of all, in step 100, the ECU 60 retrieves an after-force-feed fuel pressure PCPR and a before-force-feed fuel pressure PCRI from the memory 64. Then in step 200, the before-force-feed fuel pressure PCRI is subtracted from the after-force-feed fuel pressure PCPR. The resultant value (PCPR - PCRI) of subtraction is set as an amount ΔPCPR of rise in rail pressure.

[0057] Then in step 300, the ECU 60 calculates an estimated value ΔPCPRCAL of rail pressure rise amount, in accordance with the following procedure. The estimated value ΔPCPRCAL of rail pressure rise amount is an estimated value of an amount of rise in rail pressure in a period from detection of the before-force-feed fuel pressure PCRI to detection of the after-force-feed fuel pressure PCPR (see Fig. 3: hereinafter referred to as the „rail pressure estimation period APCR").

[0058] First of all, the ECU 60 calculates a fuel force-feed amount QPUMP for the respective supply pumps 50a and 50b based on a command value for valve-closing timings of the respective adjusting valves 70a and 70b. The fuel force-feed amount QPUMP changes based on valve-closing timings of the respective adjusting valves 70a and 70b in a suc-

tion stroke prior to the start of force-feeding of fuel. Hence, if the present timing of interruption is, for example, the timing CAA2 shown in Fig. 3 and force-feeding of fuel has been carried out by the second supply pump 50b up to the timing CAA2, the ECU 60 calculates the fuel force-feed amount QPUMP based on a command value for the valve-closing timing of the second adjusting valve 70b that is set in a period from the timing CAA0 to the timing CAA1. If the timing of interruption is, for example, the timing CAA3 shown in Fig. 3 and force-feeding of fuel has been carried out by the first supply pump 50a up to the timing CAA3, the ECU 60 calculates the fuel force-feed amount QPUMP based on a command value for the valve-closing timing of the first adjusting valve 70a that is set in a period from the timing CAA1 to the timing CAA2.

[0059] Next, the ECU 60 calculates an estimated value ΔPCPRCAL of rail pressure rise amount, according to a calculation formula (1) shown below.

$$\Delta PCPRCAL = E \times (QPUMP - QLEAK)/VCR \quad (1)$$

E: volume elasticity coefficient
QPUMP: fuel force-feed amount
QLEAK: fuel leak amount
VCR: volume of the common rail 20

[0060] The volume elasticity coefficient E, which is a volume elasticity coefficient of fuel in the common rail 20, is calculated through a processing routine other than the present routine, based on a before-force-feed fuel pressure PCRI, an after-force-feed fuel pressure PCPR and a fuel temperature THF. The fuel leak amount QLEAK, which is an amount of fuel returned to the fuel tank 14 from the common rail 20 through the respective injectors 12 during the rail pressure estimation period APCR, is calculated through a processing routine other than the present routine, based on a rail pressure, a fuel temperature THF, an engine rotational speed NE and the like.

[0061] After having calculated the estimated value ΔPCPRCAL of rail pressure rise amount, the ECU 60 determines in step 400 whether or not the determination counter value CPCYLND is „1" or „3", namely, whether or not the fuel force-feed period immediately before the present timing of interruption is a period in which fuel has been force-fed from the first fuel force-feed system.

[0062] If the result is affirmative in step 400, the ECU 60 shifts its operation to step 500 where a first abnormality determining value PCRD1 for determining abnormality in the first fuel force-feed system is calculated according to a calculation formula (2) shown below.

$$PCRD1 = (\Delta PCPRCAL - \Delta PCPR) \times K + PCRD1OLD \times (1 - K) \quad (2)$$

ΔPCPRCAL: estimated value of rail pressure rise amount
ΔPCPR: rail pressure rise amount
K: constant ($0 < K < 1$)
PCRD1OLD: value of first abnormality determining value at a preceding timing of interruption

[0063] On the other hand, if the result in step 400 is negative, namely, if the fuel force-feed period immediately before the present timing of interruption is a period in which fuel has been force-fed from the second fuel force-feed system, the ECU 60 shifts its operation to step 550. In step 550, the ECU 60 calculates a second abnormality determining value PCRD2 for determining abnormality in the second fuel force-feed system, according to a calculation formula (3) shown below.

$$PCRD2 = (\Delta PCPRCAL - \Delta PCPR) \times K + PCRD2OLD \times (1 - K) \quad (3)$$

ΔPCPRCAL : estimated value of rail pressure rise amount
ΔPCPR : rail pressure rise amount
K: constant ($0 < K < 1$)
PCRD2OLD: second abnormality determining value at preceding timing of interruption

[0064] As is apparent from the aforementioned calculation formulas (2) and (3), the respective abnormality determining values PCRD1 and PCRD2 are obtained by subjecting the difference (ΔPCPRCAL - ΔPCPR) between the estimated value ΔPCPRCAL of rail pressure rise amount and the after-force-feed fuel pressure PCPR to a „smoothing processing" based on the constant K, individually for the respective fuel force-feed systems.

[0065] Further, the abnormality determining values PCRD1 and PCRD2 change depending on whether or not there is an abnormality occurring in the respective fuel force-feed systems. If there is an abnormality occurring, those abnor-

mality determining values further change depending on whether the amounts of fuel force-fed in the respective fuel force-feed systems are insufficient or excessive.

[0066] For example, if there is no abnormality occurring in the first fuel force-feed system and both the first supply pump 50a and the first adjusting valve 70a operate normally, the estimated value ΔPCPRCAL of rail pressure rise amount is equal to the rail pressure rise amount ΔPCPR. Therefore, the first abnormality determining value PCRD1 converges to „0".

[0067] Also, for example, if the first adjusting valve 70a encounters difficulty in opening due to adhesion or the like and the amount of fuel force-fed from the first fuel force-feed system is insufficient, the rail pressure, which is intrinsically to change as indicated by a solid line in Fig. 6, rises less drastically as indicated by an alternate long and short dash line in Fig. 6. Accordingly, the rail pressure rise amount ΔPCPR is smaller than the estimated value ΔPCPRCAL of rail pressure rise amount, and the first abnormality determining value PCRD1 is greater than „1".

[0068] Conversely, for example, if the first adjusting valve 70a is stuck in its open state and the amount of fuel force-fed from the first fuel force-feed system is maintained at its maximum, the rail pressure rises as indicated by an alternate long and two dashes line in Fig. 6 because fuel is constantly force-fed in the rail pressure estimation period ΔPCR. Accordingly, the rail pressure rise amount ΔPCPR is greater than the estimated value ΔPCPRCAL of rail pressure rise amount, and the first abnormality determining value PCRD1 is smaller than „0".

[0069] Accordingly, it can be determined based on the first abnormality determining value PCRD1 whether or not there is an abnormality occurring in the first fuel force-feed system. Further, if there is an abnormality occurring, it can also be determined based on the first abnormality determining value PCRD1 whether the amount of fuel force-fed from the fuel force-feed system is insufficient or excessive. The same is true with the relationship between the second abnormality determining value PCRD2 and the second fuel force-feed system.

[0070] In making such determinations, the „smoothing processing" as described above may be omitted, and the respective abnormality determining values PCRD1 and PCRD2 may simply be set to a difference between the estimated value ΔPCPRCAL of rail pressure rise amount and rail pressure rise amount ΔPCPR (PCRD1, PCRD2 = ΔPCPRCAL - ΔPCPR). Even in the case where the detection values of rail pressure (the before-force-feed fuel pressure PCRI, the after-force-feed fuel pressure PCPR) temporarily fluctuate independently of states of the respective fuel force-feed systems, performance of the „smoothing processing" can inhibit the respective abnormality determining values PCRD1 and PCRD2 from changing due to the fluctuation.

[0071] After the respective abnormality determining values PCRD1 and PCRD2 have thus been calculated in step 500 or 550, in step 510 or 560 that follows, the abnormality determining values PCRD1 and PCRD2 that have been calculated this time are set to previous values PCRD1OLD and PCRD2OLD respectively in preparation for the subsequent processing.

[0072] Then in processings after step 600, the ECU 60 determines abnormality in the respective fuel force-feed systems by comparing the respective abnormality determining values PCRD1 and PCRD2 with a plurality of predetermined values α, β and γ.

[0073] Fig. 7 shows a relationship between the aforementioned respective predetermined values α, β and γ and patterns of abnormality.

[0074] As shown in Fig. 7, if the abnormality determining values PCRD1 and PCRD2 are greater than the first predetermined value α (> 0), it is determined that the amounts of fuel force-fed from the fuel force-feed systems are insufficient. Conversely, if absolute values | PCRD1 | and | PCRD2 | of the abnormality determining values PCRD1 and PCRD2 are equal to or smaller than the second predetermined value β ($0 < \alpha < \beta$), namely, if the relationship of($-\beta \leq$ PCRD1 $\leq \beta$, $-\beta \leq$ PCRD2 $\leq \beta$) is established, it is determined that there is no abnormality occurring in the fuel force-feed systems. Furthermore, if the abnormality determining values PCRD1 and PCRD2 are smaller than the third predetermined value γ (< 0), it is determined that the amounts of fuel force-fed from the fuel force-feed systems are excessive.

[0075] By comparing thus-obtained results of abnormality determination with one another, the ECU 60 then specifies the type of the abnormality occurring. This processing will be described hereinafter in further detail.

[0076] First of all, in step 600, the respective abnormality determining values PCRD1 and PCRD2 are compared with the first predetermined value α. It is determined in step 600 whether or not both the abnormality determining values PCRD1 and PCRD2 are greater than the first predetermined value α, namely, whether or not the amounts of fuel force-fed from both the fuel force-feed systems are insufficient.

[0077] If the result is affirmative in step 600, there is actually very little possibility that there is an abnormality occurring almost simultaneously in both the fuel force-feed systems. Therefore, in specifying the type of the abnormality, the ECU 60 determines that there is fuel leakage or operational failure occurring in a mechanism commonly used for both the fuel force-feed systems. Then in step 610, the ECU 60 turns on a first abnormality flag X1 corresponding to the type of the abnormality, and stores the state of the flag X1 into the memory 64.

[0078] The fuel leakage in the mechanism commonly used for both the fuel force-feed systems includes:

leakage of fuel from the common rail 20, the discharge passage 23 and the relief valve 22; and
excessive leakage of fuel from the injectors 12.

[0079] The operational failure in the mechanism commonly used for both the fuel force-feed systems includes:

deterioration of fuel supplying performance of the feed pump 31; and
sticking of the relief valve 32 in its open state.

[0080] The ECU 60 then shifts its operation to step 620. In step 620, the ECU 60 forcibly suspends operation of the engine 10 by suspending fuel injection from the respective injectors 12. As a result, force-feeding of fuel from the fuel pump 30 is suspended, and fuel in the common rail 20 is gradually returned to the fuel tank 14 through leakage of fuel from the respective injectors 12. Therefore, the rail pressure decreases. Accordingly, even if there is fuel leaking out from the common rail 20 and the like, the amount of fuel leakage can be minimized.

[0081] On the other hand, if the result in step 600 is negative, the ECU 60 determines in step 700 shown in Fig. 5 whether or not the amount of fuel force-fed from the first fuel force-feed system is insufficient and there is no abnormality occurring in the second fuel force-feed system, by comparing the first abnormality determining value PCRD1 with the first predetermined value α and the absolute value |PCRD2| of the second abnormality determining value PCRD2 with the second predetermined value β.

[0082] If the result is affirmative in step 700, the ECU 60 specifies the type of the abnormality by determining that the force-feed performance of the first supply pump 50a has deteriorated or that there is some abnormality occurring in the first adjusting valve 70a. Then in step 710, the ECU 60 turns on a second abnormality flag X2 corresponding to the type of the abnormality, and stores the state of the flag X2 into the memory 64.

[0083] If the result is negative in step 700, the ECU further determines in step 800 whether or not the amount of fuel force-fed from the second fuel force-feed system is insufficient and there is no abnormality occurring in the first fuel force-feed system, by comparing the second abnormality determining value PCRD2 with the first predetermined value a and the absolute value |PCRD1| of the first abnormality determining value PCRD1 with the second predetermined value β.

[0084] If the result in step 800 is affirmative, the ECU 60 specifies the type of the abnormality by determining that the force-feed performance of the second supply pump 50b has deteriorated or that there is some abnormality occurring in the second adjusting valve 70b. Then in step 810, the ECU 60 turns on a third abnormality flag X3 corresponding to the state of the abnormality, and stores the state of the flag X3 into the memory 64.

[0085] The deterioration of the force-feed performance of the supply pumps 50a and 50b as specified in steps 710 and 810 respectively includes:

halt of reciprocating movements of the plungers 54a and 54b of the supply pumps 50a and 50b due to interlocking or the like; and
sticking of the check valves 44a, 44b, 46a and 46b in their open or closed states.

[0086] The abnormality in the adjusting valves 70a and 70b includes:

inability to open the adjusting valves 70a and 70b due to adhesion, breaking of wires or the like; and
extreme deterioration of response property of opening movements of the adjusting valves 70a and 70b.

[0087] If the result in step 700 and the result in step 800 are both negative, the ECU 60 shifts its operation to step 900. In step 900, the ECU 60 determines whether or not the amount of fuel force-fed from the first fuel force-feed system is excessive and there is no abnormality occurring in the second fuel force-feed system, by comparing the first abnormality determining value PCRD1 with the third predetermined value γ and the absolute value |PCRD2| of the second abnormality determining value PCRD2 with the second predetermined value β.

[0088] If the result in step 900 is affirmative, the amount of fuel force-fed from the first supply pump 50a is excessive. Thus, it can be determined that the force-feed performance of the first supply pump 50a has not deteriorated. Accordingly, in this case, the ECU 60 specifies the type of the abnormality by determining that there is some abnormality occurring only in the first adjusting valve 70a. Then in step 910, the ECU 60 turns on an abnormality flag X4 corresponding to the type of the abnormality, and stores the state of the flag X4 into the memory 64.

[0089] Then in step 915, the ECU 60 forcibly suspends force-feeding of fuel from the first supply pump 50a by stopping supplying electric power to the first adjusting valve 70a and constantly keeping the first adjusting valve 70a closed.

[0090] If the result is negative in step 900, the ECU 60 determines in step 1000 whether or not the amount of fuel force-fed from the second fuel force-feed system is excessive and there is no abnormality occurring in the first fuel force-feed system, by comparing the second abnormality determining value PCRD2 with the third predetermined value

γ and the absolute value |PCRD1| of the first abnormality determining value PCRD1 with the second predetermined value β.

[0091] If the result in step 1000 is affirmative, the ECU 60 specifies the type of the abnormality by determining that there is some abnormality occurring in the second adjusting valve 70b. Then in step 1010, the ECU 60 turns on a fifth abnormality flag X5 corresponding to the type of the abnormality, and stores the state of the flag X5 into the memory 64.

[0092] Then in step 1015, the ECU 60 forcibly suspends force-feeding of fuel from the second supply pump 50b by stopping supplying electric power to the second adjusting valve 70b and constantly keeping the second adjusting valve 70b closed.

[0093] The abnormality of the adjusting valves 70a and 70b as specified in steps 910 and 1010 respectively includes the case where the adjusting valves 70a and 70b have been stuck in their open states and the amounts of fuel force-fed from the supply pumps 50a and 50b are maintained at their maximum.

[0094] After having carried out any of the processings in steps 915 and 1015, the ECU 60 shifts its operation to step 920. In step 920, the ECU 60 restricts an output of the engine 10 by setting an upper limit value of fuel injection amount. Due to such restriction of the fuel injection amount, the required amount of fuel to be force-fed from the fuel pump 30 decreases relatively. Through one of the processings in steps 915 and 1015, fuel is force-fed from one of the respective supply pumps 50a and 50b. However, by reducing the required amount of fuel force-fed as described above, it becomes possible to inhibit an excessively high load from being applied to one of the supply pumps 50a and 50b that performs force-feeding of fuel.

[0095] After having carried out any of the processings in steps 620, 710, 810 and 920, or after having made a negative determination in step 1000, the ECU 60 temporarily terminates the processings of the present routine.

[0096] As described hitherto, in the present embodiment, the occurrence of abnormality is determined individually for the respective fuel force-feed systems, by determining which of the fuel force-feed systems is in the process of force-feeding fuel in a fuel force-feed period.

[0097] Accordingly, the occurrence of abnormality in the respective fuel force-feed systems can be determined individually, for example, by forcibly suspending force-feeding of fuel from the respective fuel force-feed systems and without changing operational states thereof. Consequently, without causing fluctuations of rail pressure, a fuel force-feed system subject to abnormality can be specified. Therefore, it is possible to prevent the precision of fuel injection control from deteriorating due to fluctuations of rail pressure and the combustion state of the engine from deteriorating correspondingly.

[0098] Also, since the rail pressure is prevented from fluctuating, the occurrence of an abnormality can be determined every time fuel injection is carried out. That is, the frequency of determination of abnormality can be increased to a certain extent. As a result, it is possible to determine the occurrence of an abnormality in the fuel force-feed systems at an earlier stage, and to start fail-safe processings such as suspension of operation of the engine and restriction of the engine output at an earlier stage.

[0099] Furthermore, the amount of rise in rail pressure is estimated based on the command values for the fuel force-feed systems, namely, on the command values for the valve-closing timings of the respective adjusting valves 70a and 70b, and the occurrence of an abnormality is determined based on a difference between the estimated value (the estimated value ΔPCPRCAL of rail pressure rise amount) and an actual measurement value (the rail pressure rise amount ΔPCPR). Therefore, the reliability of the result of abnormality determination can be enhanced.

[0100] In particular, by comparing the difference (the respective abnormality determining values PCRD1 and PCRD2) between the estimated value and the actual measurement value with the predetermined values α, β and γ, it becomes possible not only to determine whether or not there is an abnormality occurring but also to determine in detail whether the amount of fuel force-fed from the fuel force-feed system subject to the abnormality is insufficient or excessive.

[0101] Further, the results of abnormality determination in the respective fuel force-feed systems, namely, the results of comparison of the respective abnormality determining values PCRD1 and PCRD2 with the predetermined values α, β and γ are compared with one another. Therefore, it is also possible to specify the type of the abnormality.

[0102] That is, the determination of abnormality can specifically be classified into the following patterns.

(1) If the amounts of fuel force-fed from both the fuel force-feed systems are insufficient, fuel leakage or operational failure has occurred in the mechanism commonly used for both the fuel force-feed systems.

(2) If the amount of fuel force-fed from the first fuel force-feed system is insufficient and there is no abnormality occurring in the second fuel force-feed system, the force-feed performance of the first supply pump 50a has deteriorated or there is an abnormality occurring in the first adjusting valve 70a.

(3) If the amount of fuel force-fed from the second fuel force-feed system is insufficient and there is no abnormality occurring in the first fuel force-feed system, the force-feed performance of the second supply pump 50b has deteriorated or there is an abnormality occurring in the second adjusting valve 70b.

(4) If the amount of fuel force-fed from the first fuel force-feed system is excessive and there is no abnormality

occurring in the second fuel force-feed system, there is an abnormality occurring in the first adjusting valve 70a.

(5) If the amount of fuel force-fed from the second fuel force-feed system is excessive and there is no abnormality occurring in the first fuel force-feed system, there is an abnormality occurring in the second adjusting valve 70b.

[0103] Accordingly, appropriate fail-safe processings such as suspension of operation of the engine and restriction of the engine output can be performed depending on the various types of abnormality as described above.

[0104] Especially, the respective abnormality determining values PCRD1 and PCRD2 are calculated by subjecting the difference (the estimated value ΔPCPRCAL of rail pressure rise amount - the rail pressure rise amount ΔPCPR) between the estimated value and the actual measurement value to the „smoothing processing". Therefore, even if the detection values of rail pressure (the before-force-feed fuel pressure PCRI, the after-force-feed fuel pressure PCPR) have fluctuated independently of the respective fuel force-feed systems, the abnormality determining values PCRD1 and PCRD2 are inhibited from changing due to the fluctuation. Thus, the determination of abnormality can be performed with higher precision, and the reliability of the result of abnormality determination can be enhanced.

[0105] Further, if the amounts of fuel force-fed from the respective fuel force-feed systems are both determined to be insufficient, operation of the engine 10 is forcibly suspended as the fail-safe processing, whereby the rail pressure is reduced swiftly. Therefore, even if there is fuel leaking out from the common rail 20 or the like, the amount of fuel leakage can be minimized.

[0106] Furthermore, if the amount of fuel force-fed from only one of the fuel force-feed systems is determined to be excessive due to sticking of the first adjusting valve 70a or the second adjusting valve 70b in its open state or the like, operation of the fuel force-feed system subject to the abnormality is suspended and the engine output is restricted as the fail-safe processing, whereby the required amount of fuel to be force-fed is reduced. Accordingly, even after the suspension of the operation, it is possible to inhibit an excessively high load from being applied to the fuel force-feed system that performs force-feeding of fuel, and to prevent the occurrence of a secondary abnormality such as a failure in the fuel force-feed systems.

[0107] Further, when there is an abnormality occurring, one of the abnormality flags X1 through X5 corresponding to the type of the abnormality is turned on. Thus, by checking contents of those abnormality determining flags X1 through X5, for example, at the time of maintenance, the location of a failure and a cause thereof can easily be identified. As a result, failure analysis and maintenance operations can be carried out with perfect ease.

[0108] In the aforementioned embodiment, the amount of rise in rail pressure is estimated based on the command values for the valve-closing timings of the respective adjusting valves 70a and 70b, and the estimated value (the estimated value ΔPCPRCAL of rail pressure rise amount) is compared with the actual measurement value (the rail pressure rise amount ΔPCPR) so as to determine whether or not there is an abnormality occurring. However, those command values may directly be compared with the actual measurement value so as to determine the occurrence of an abnormality.

[0109] In the aforementioned embodiment, the valve-closing timings of the respective adjusting valves 70a and 70b are limited within a certain range so as to prevent force-feeding of fuel and fuel injection from being carried out simultaneously. However, the method of determining abnormality according to the present embodiment can also be applied to a high-pressure fuel injection device wherein the period of force-feeding of fuel overlaps with the period of fuel injection. In this case, a processing of determining whether or not the period of force-feeding of fuel overlaps with the period of fuel injection is performed, for example, prior to the performance of the processing of step 100 in the „abnormality determining routine" shown in Fig. 4. Only if it is determined that those periods do not overlap with each other, the processings following step 100 are performed.

[0110] In the aforementioned embodiment, all the processings (1) through (5) for specifying the type of the abnormality are performed. However, it is also possible to perform only one or some of those processings.

[0111] In the aforementioned embodiment, when any one of the abnormality flags X1 through X5 is turned on, a warning lamp indicative of the occurrence of an abnormality may be lit.

[0112] In the aforementioned embodiment, the estimated value of rail pressure rise amount is compared with the actual measurement value of rail pressure rise amount so as to determine the occurrence of the abnormality. However, for example, the determination can also be made by comparing estimated and actual measurement values of a rate of change in rail pressure or a pattern of change in rail pressure, with each other.

[0113] Furthermore, such comparison of the estimated value with the actual measurement value may be omitted. That is, it is also possible to compare the actual measurement value simply with a predetermined threshold value so as to determine whether or not the rail pressure has risen.

[0114] The high-pressure fuel injection device provided with two fuel force-feed systems has been described in the aforementioned embodiment. However, the present invention can also be applied to a high-pressure fuel injection device provided with three or more fuel force-feed systems. In this case, if any two of fuel force-feed periods of the respective fuel force-feed systems overlap with each other, an operation is performed to find a period in which there is no such overlapping and one of the fuel force-feed systems alone performs force-feeding of fuel. In the thus-found

period, the occurrence of an abnormality is determined.

[0115] In the aforementioned embodiment, the rail pressure rise amount is estimated based on the fuel force-feed amount QPUMP and the fuel leak amount QLEAK. However, if the fuel leak amount QLEAK is much smaller than the fuel force-feed amount QPUMP, the rail pressure rise amount may be estimated based on only the fuel force-feed amount QPUMP.

[0116] The aforementioned embodiment deals with a diesel engine as an internal combustion engine. However, the method of determining abnormality according to the present invention can also be applied to, for example, a high-pressure fuel injection device of a cylinder direct injection gasoline engine wherein fuel is directly injected to combustion chambers.

Claims

1. A method of determining abnormality in a high-pressure fuel injection device having a plurality of fuel force-feed systems for force-feeding high-pressure fuel in individual force-feed periods to an accumulator line to which fuel injection valves of an internal combustion engine are connected, characterized by comprising the steps of:

   determining which one of the fuel force-feed systems is in a force-feed period at a timing when determination of abnormality is made (S400); and
   determining whether or not there is an abnormality occurring in each of the fuel force-feed systems (S600, S700, S800, S900, S1000).

2. The method according to claim 1, characterized by further comprising the steps of:

   detecting a change in fuel pressure in the accumulator line during the force-feed period (S200); and
   determining whether or not the abnormality has occurred, based on comparison of a result of detection with a force-feed command value for the corresponding one of the fuel force-feed systems.

3. The method according to claim 1, characterized by further comprising the steps of:

   detecting a change in fuel pressure in the accumulator line in the force-feed period;
   estimating a change in fuel pressure in the force-feed period subject to determination, based on a force-feed command value for the corresponding one of the fuel force-feed systems (S300); and
   determining whether or not the abnormality has occurred, based on comparison of the estimated change in fuel pressure with the detected change in fuel pressure.

4. The method according to claim 3, characterized by further comprising the step of:

   determining, as the abnormality, that an amount of fuel force-fed from the fuel force-feed system is either insufficient or excessive, by comparing the detected change amount of fuel pressure with the estimated change amount of fuel pressure.

5. The method according to claim 4, characterized by further comprising the step of:

   specifying a type of the abnormality by comparing results of determination of abnormality in the respective fuel force-feed systems with one another.

6. The method according to claim 5, characterized by further comprising the step of:

   specifying a type of the abnormality by determining, when the results of determination of abnormality demonstrate insufficiency of amounts of fuel force-fed from only one or some of the fuel force-feed systems, at least either that force-feed performance of force-feed mechanisms provided in said one or some of the fuel force-feed systems so as to pressurize fuel and force-feed the fuel to the accumulator line has deteriorated or that there is an abnormality occurring in adjusting mechanisms for adjusting amounts of fuel force-fed from said one or some of the fuel force-feed systems.

7. The method according to claim 5, characterized:

   in that the fuel force-feed systems are provided with force-feed mechanisms which pressurize fuel and force-

feed the fuel to the accumulator, and provided with adjusting mechanism for adjusting amount of the fuel; and by further comprising the step of specifying a type of the abnormality by determining, when the results of determination of abnormality demonstrate excess of amounts of fuel force-fed from only one or some of the fuel force-feed systems, that there is an abnormality occurring in adjusting mechanisms for adjusting amounts of fuel force-fed from force-feed mechanisms provided in said one or some of the fuel force-feed systems so as to pressurize fuel and force-feed the fuel to the accumulator line.

8. The method according to claim 5, characterized by further comprising the step of:

specifying a type of the abnormality by determining, when the results of determination of abnormality demonstrate insufficiency of amounts of fuel force-fed from all the fuel force-feed systems, that at least one of fuel leakage and operational failure is present in a mechanism common to the fuel force-feed systems.

9. The method according to any of claims 1 to 3, characterized by further comprising the step of:

additionally determining, when the results of determination of abnormality in the respective fuel force-feed systems demonstrate occurrence of an abnormality in all the fuel force-feed systems, that there is an abnormality occurring in the mechanism common to the fuel force-feed systems.

10. The method according to any of claims 1 to 9, characterized by further comprising the step of:

performing individual determination of abnormality in the respective fuel force-feed systems every time fuel injection from the fuel injection valves is

carried out.

FIG. 1

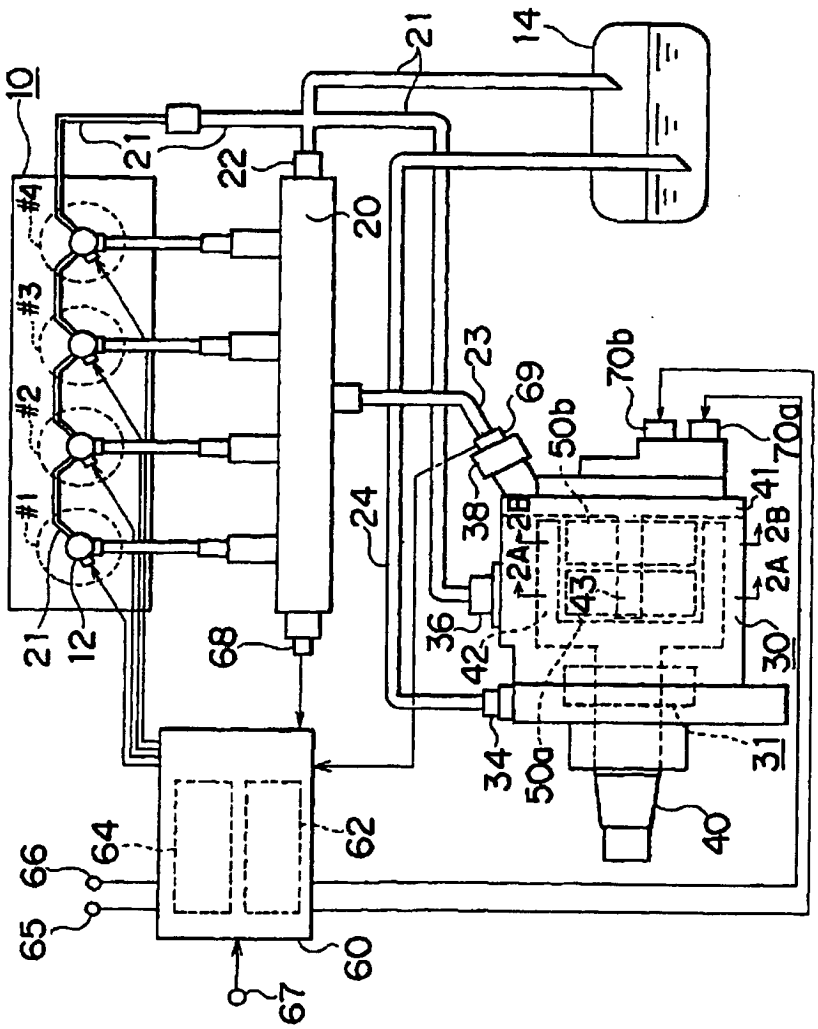
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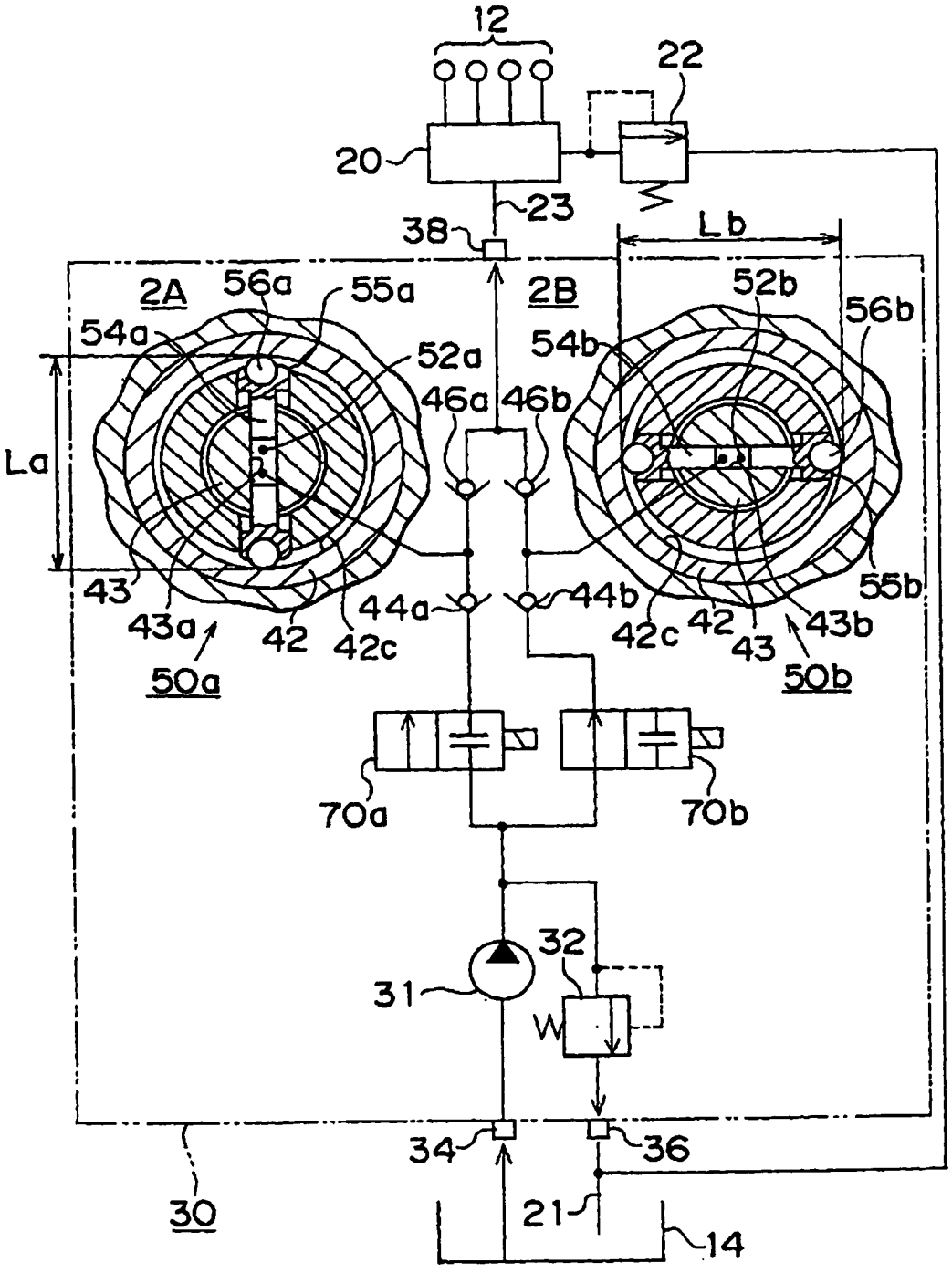
FIG. 2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44b
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21
14

FIG. 3

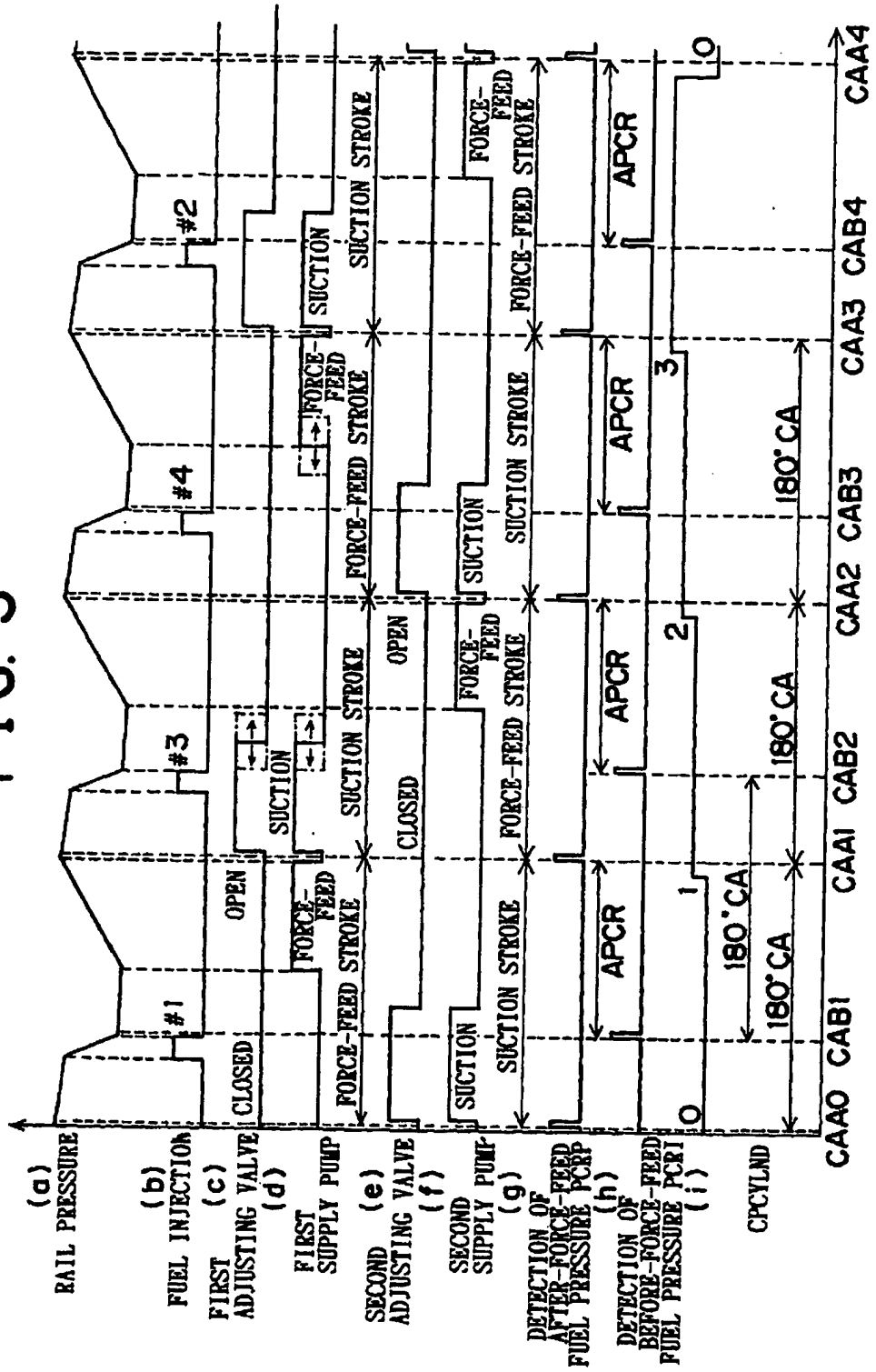

(a) RAIL PRESSURE
(b) FUEL INJECTION
(c) FIRST ADJUSTING VALVE
(d) FIRST SUPPLY PUMP
(e) SECOND ADJUSTING VALVE
(f) SECOND SUPPLY PUMP
(g) DETECTION OF AFTER-FORCE-FEED FUEL PRESSURE PCRP
(h) DETECTION OF BEFORE-FORCE-FEED FUEL PRESSURE PCRI
(i) CPCYLND
#1
#2
#3
#4
CLOSED
OPEN
SUCTION
FORCE-FEED
FORCE-FEED STROKE
SUCTION STROKE
APCR
180°CA
0
1
2
3
CAA0 CAB1 CAA1 CAB2 CAA2 CAB3 CAA3 CAB4 CAA4

FIG. 4

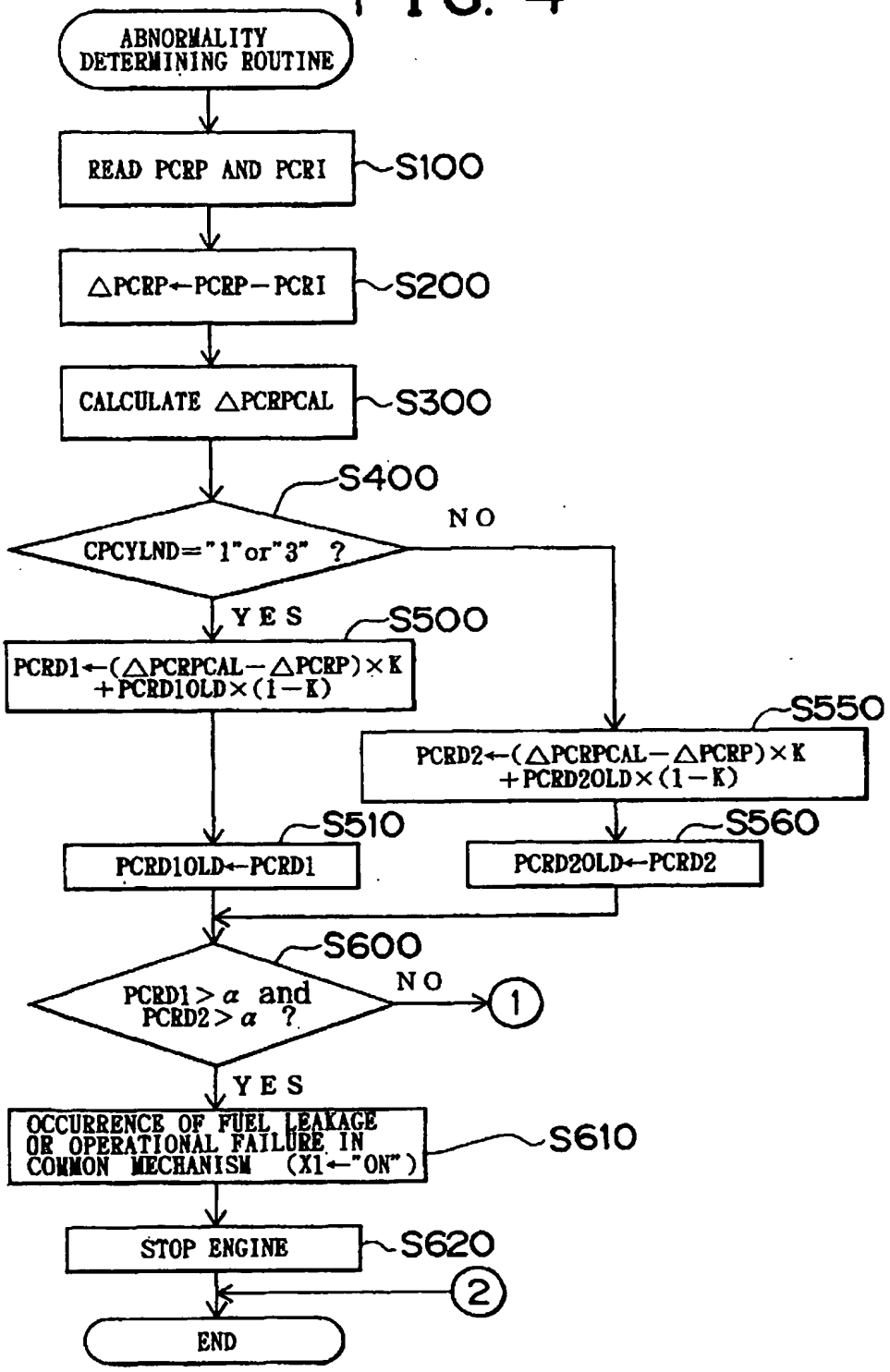

ABNORMALITY DETERMINING ROUTINE
READ PCRP AND PCRI
S100
ΔPCRP←PCRP−PCRI
S200
CALCULATE ΔPCRPCAL
S300
S400
CPCYLND="1"or"3" ?
NO
YES
S500
PCRD1←(ΔPCRPCAL−ΔPCRP)×K +PCRD1OLD×(1−K)
S550
PCRD2←(ΔPCRPCAL−ΔPCRP)×K +PCRD2OLD×(1−K)
S510
PCRD1OLD←PCRD1
S560
PCRD2OLD←PCRD2
S600
PCRD1 > α and PCRD2 > α ?
NO
1
YES
OCCURRENCE OF FUEL LEAKAGE OR OPERATIONAL FAILURE IN COMMON MECHANISM (X1←"ON")
S610
STOP ENGINE
S620
2
END

FIG. 5

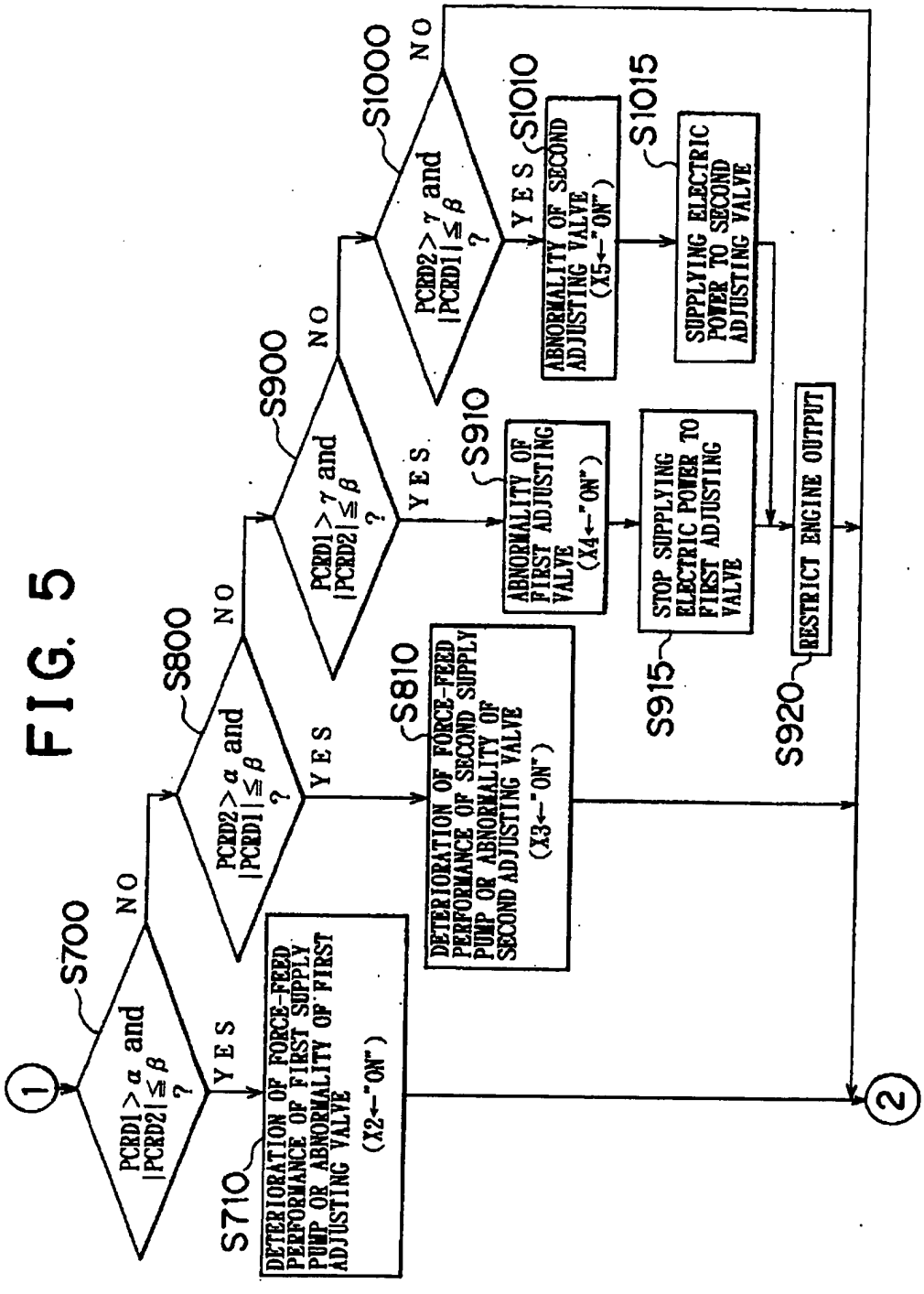

①
S700
|PCRD1| > α and |PCRD2| ≦ β ?
NO
YES
S710
DETERIORATION OF FORCE-FEED PERFORMANCE OF FIRST SUPPLY PUMP OR ABNORMALITY OF FIRST ADJUSTING VALVE (X2←"ON")
S800
|PCRD2| > α and |PCRD1| ≦ β ?
NO
YES
S810
DETERIORATION OF FORCE-FEED PERFORMANCE OF SECOND SUPPLY PUMP OR ABNORMALITY OF SECOND ADJUSTING VALVE (X3←"ON")
S900
|PCRD1| > γ and |PCRD2| ≦ β ?
NO
YES
S910
ABNORMALITY OF FIRST ADJUSTING VALVE (X4←"ON")
S915
STOP SUPPLYING ELECTRIC POWER TO FIRST ADJUSTING VALVE
S1000
|PCRD2| > γ and |PCRD1| ≦ β ?
NO
YES
S1010
ABNORMALITY OF SECOND ADJUSTING VALVE (X5←"ON")
S1015
SUPPLYING ELECTRIC POWER TO SECOND ADJUSTING VALVE
S920
RESTRICT ENGINE OUTPUT
②

FIG. 6

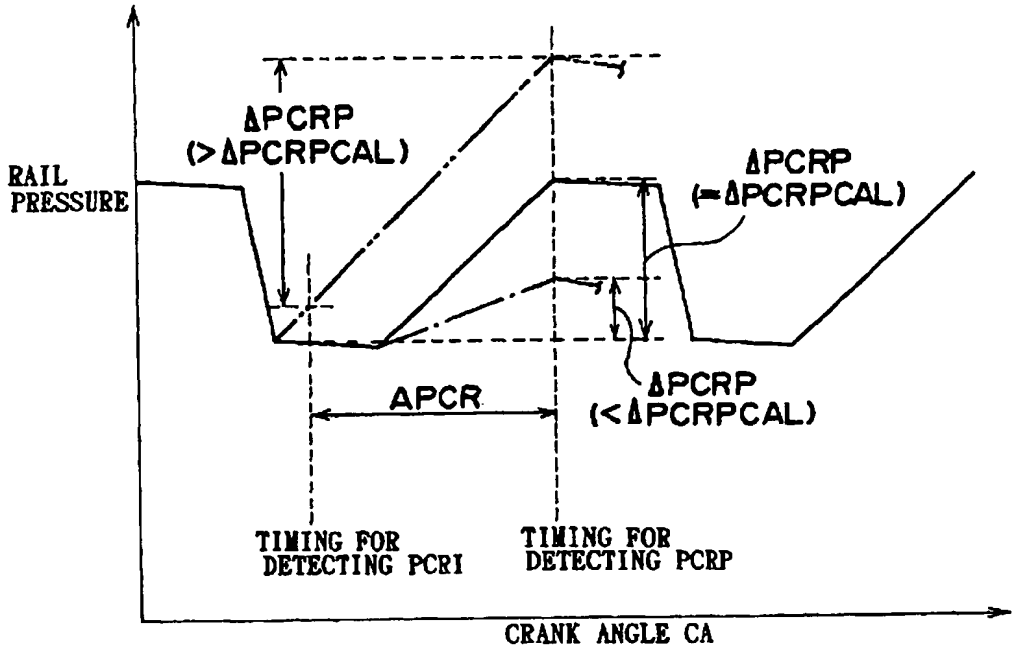
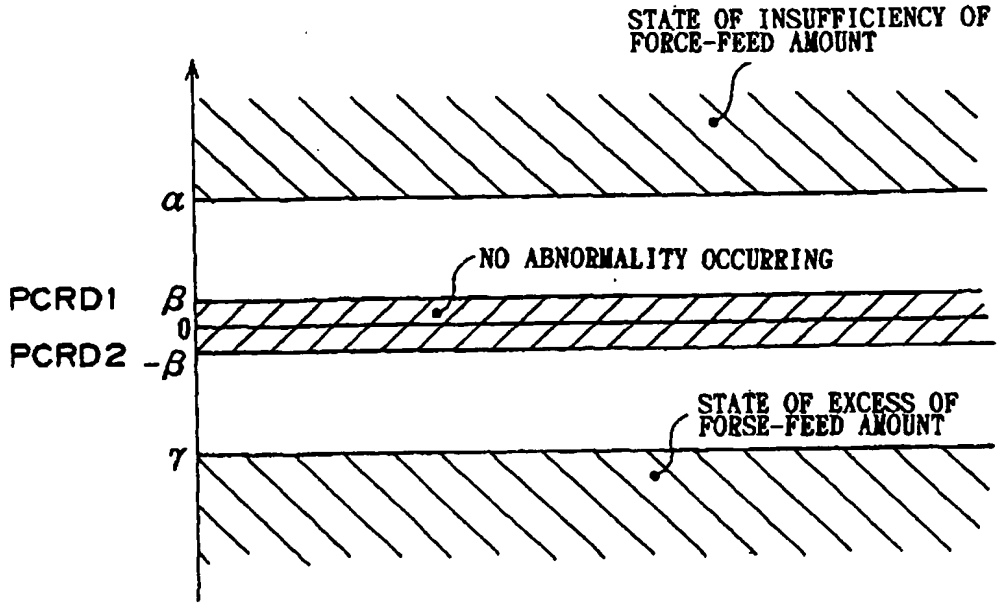

RAIL PRESSURE
ΔPCRP (>ΔPCRPCAL)
ΔPCRP (=ΔPCRPCAL)
ΔPCRP (<ΔPCRPCAL)
APCR
TIMING FOR DETECTING PCRI
TIMING FOR DETECTING PCRP
CRANK ANGLE CA

FIG. 7


STATE OF INSUFFICIENCY OF FORCE-FEED AMOUNT
α
NO ABNORMALITY OCCURRING
PCRD1
β
0
PCRD2
-β
STATE OF EXCESS OF FORSE-FEED AMOUNT
γ

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